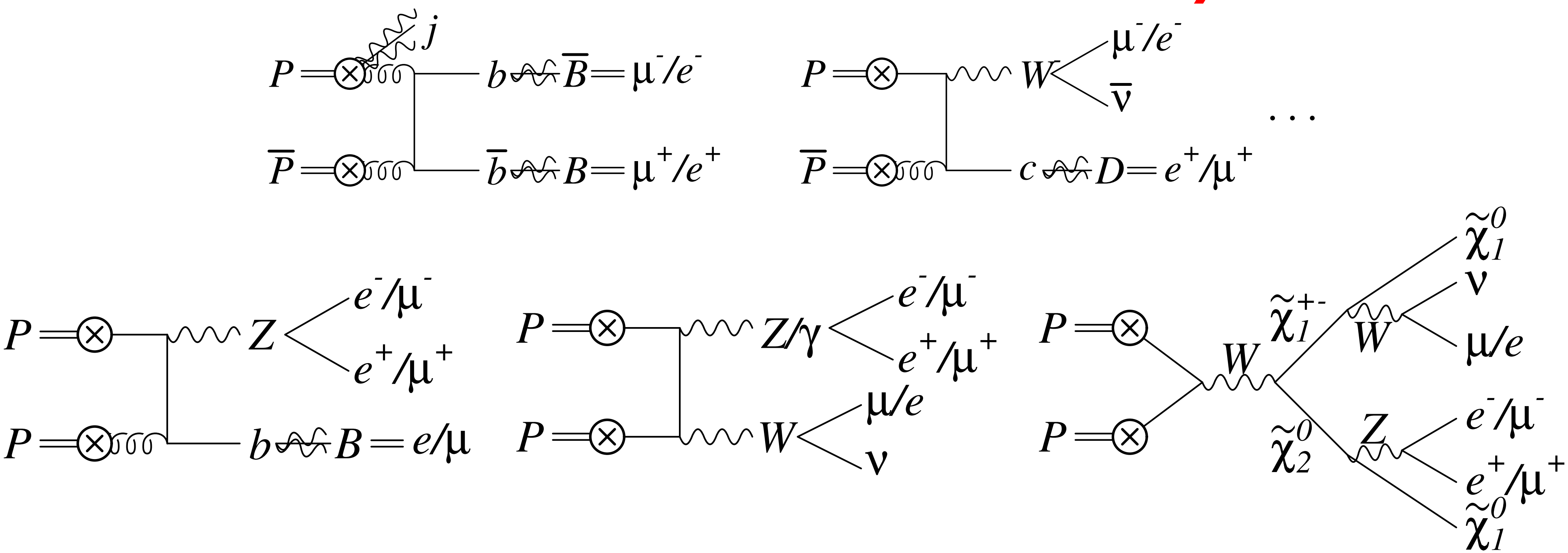
Dilepton and Trilepton Production

Standard model sources and beyond



Zack Sullivan

Illinois Institute of Technology

Based on Z.S., E. Berger, PRD **74**, 033008 (06); PRD **78** 034030 (08); and hep-ph:0912.xxxx

Thanks

The following provided valuable insight and support for Monte Carlo programs or experimental details:

John Campbell

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Tim Stelzer

John Strologas

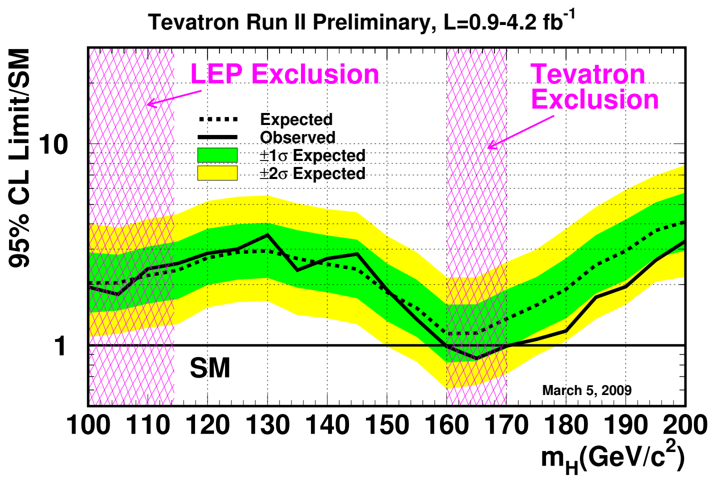
Barry Wicklund

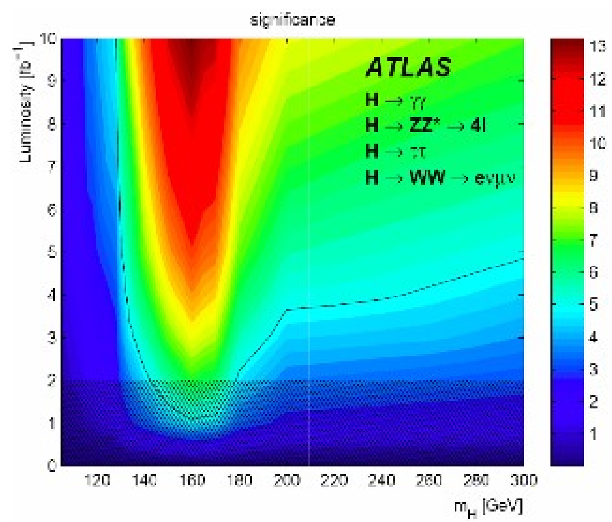
The Argonne Laboratory Computing Resource Center for 5 CPU-years of time on the JAZZ cluster.

Isolated leptons play a central role in searches for new physics

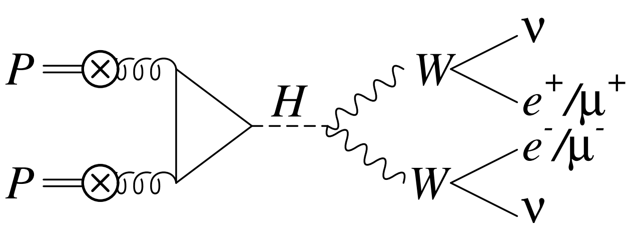
Higgs production — the excitement

The search for the Higgs boson has driven the field of high energy physics for a long time. Now we approach the Age of Discovery.





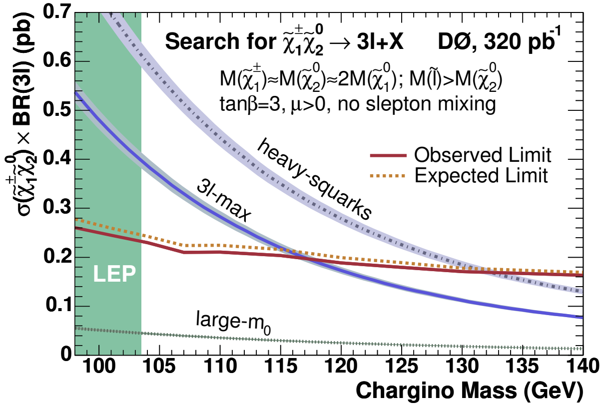
The Tevatron is in a race to find a SM Higgs before LHC first reports, while the LHC promises an "easy" observation if the Higgs is there.

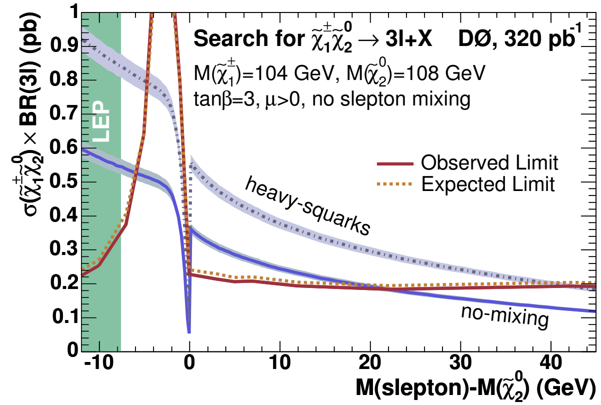


$H \to WW \to l^+ l^- \not\!\!E_T$ depends on a sophisticated understanding of low-momentum leptons and their backgrounds.

SUSY trilepton production — the “golden channel”

The measurement of trileptons plus missing energy is expected to be a clean probe of chargino and neutralino production.

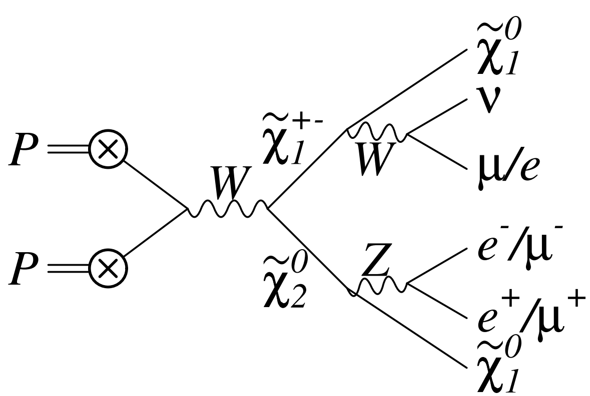


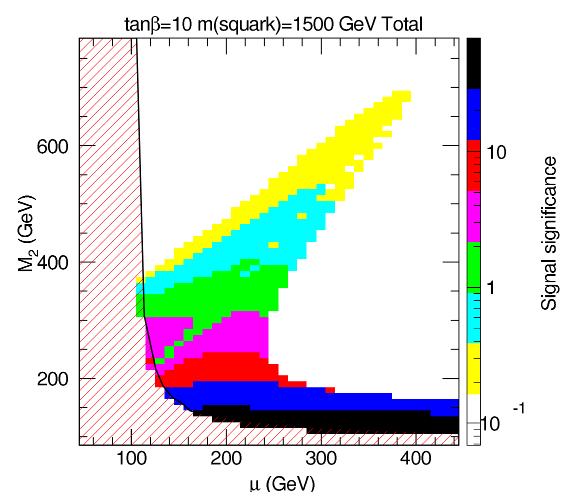


DØ, PRL95, 151805 (05)

DØ and CDF (PRD77,052002(08)) hope to both discover supersymmetry in an excess of trilepton events, and extract mass information.

CMS and ATLAS hope to do the same.





W. Vandelli, thesis

The common thread: multi-leptons+$\not\!\!E_T$

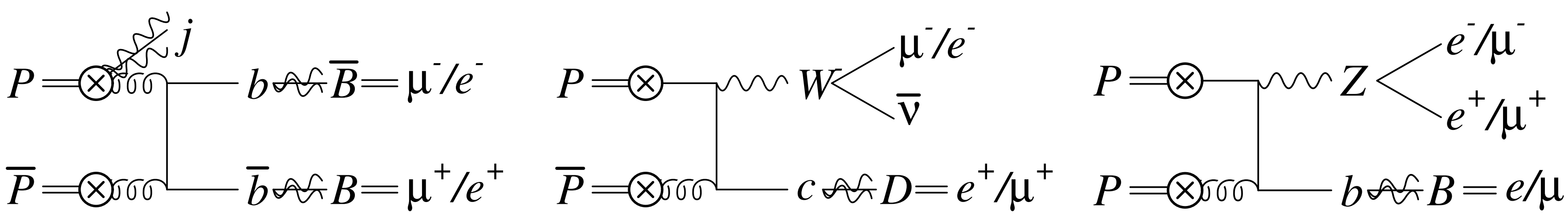
$H \to WW$ and $\widetilde{\chi}_1^+ \widetilde{\chi}_2^0$ signals share the common trait of multiple leptons plus missing transverse energy.

Experimental collaborations have spent significant time modeling (and measuring) backgrounds to these processes, including both real Standard Model physics and complicated experimental effects (e.g., jet fakes, misreconstruction, etc.)

In all cases, the background to multilepton signatures from the decays of heavy-flavor quarks (b, c) were declared "obviously" insignificant.

$\Rightarrow$ RULE of THUMB: All jet signals fake leptons at 10^{-4}.

Is this really true? The real physical processes below do not matter?



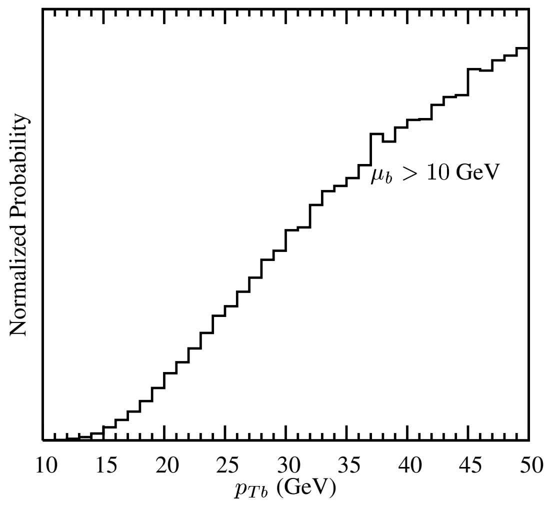
Outline

1. How heavy flavors (b, c) yield isolated leptons
2. Dileptons
   - $H \to WW$ vs. leptons from heavy flavors at the Tevatron (DØ) and LHC (ATLAS)
3. Trileptons
   - $\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0$ (The "Golden" SUSY channel) vs. leptons from heavy flavors at LHC (CMS)
4. Isolated leptons in Tevatron data
   - Measurement of $b\bar{b}$ to isolated muons (CDF)
5. Conclusions

The physics of isolated leptons from heavy-flavor decays

Z.S., E. Berger, PRD 78, 034030 (2008)

Physics of isolated leptons from b decay



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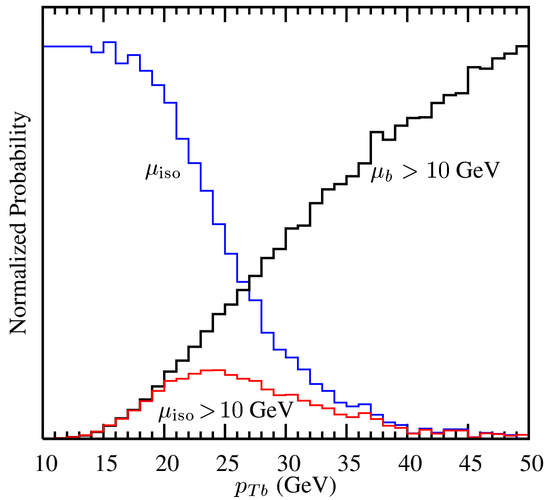


Prob. isolated muon

$= $ Prob. producing muon

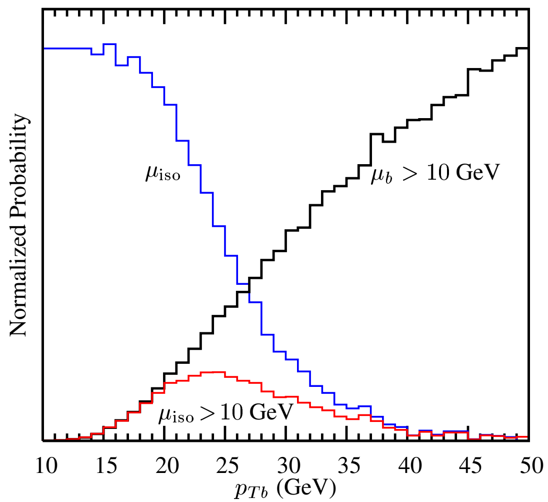
$\times$ Prob. B remnants missed

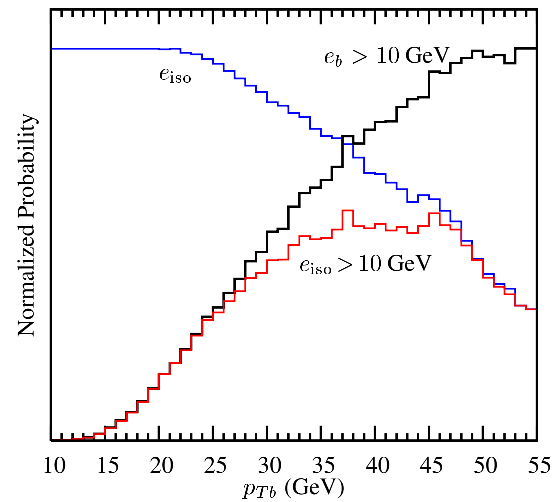
- Muons that pass isolation take large fraction of p_T
- Many isolated muons point back to primary vertex.

C. Wolfe, CDF internal

- Isolation leaves $\sim 7.5 \times 10^{-3}\ \mu/b$ $\gg 10^{-4}$ per light jet

Physics of isolated leptons from b decay





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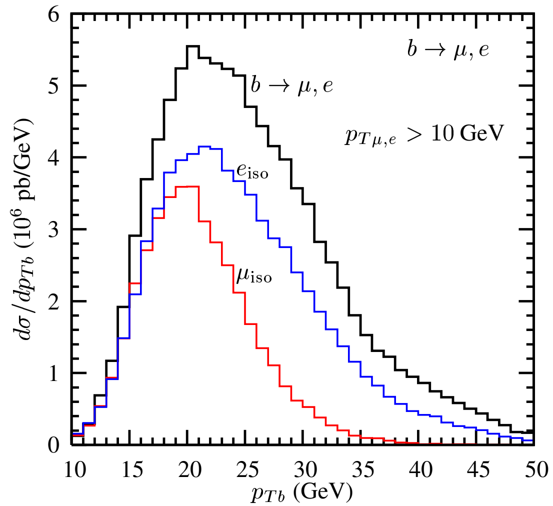
Harder b's can give isolated e's, because e cuts must allow more energy in the calorimeter

It is difficult to reduce this without losing efficiency for primary e.

Isolation is not extremely effective for leptons from b decay.

Isolated leptons from b/c production & decay



Fold in $b\bar{b}$ production.

- A large fraction of events with $b \to \mu/e$ have isolated μ/e.

  More isolated e than μ per b.

- $1/2$ of all isolated μ come from b with $p_{Tb} < 20$ GeV.

  It is common for analyses to start simulations with $p_{Tb} > 20$ GeV.

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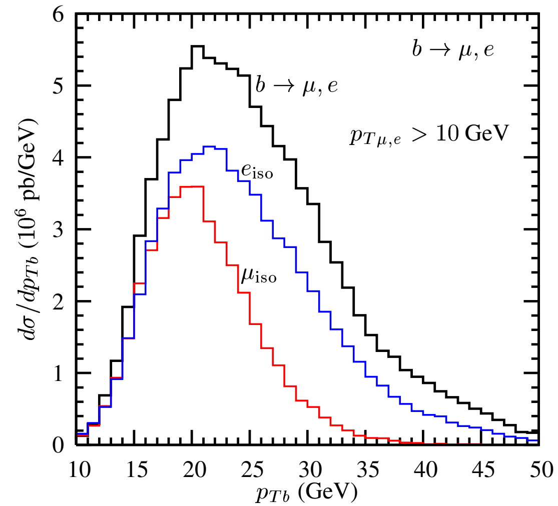

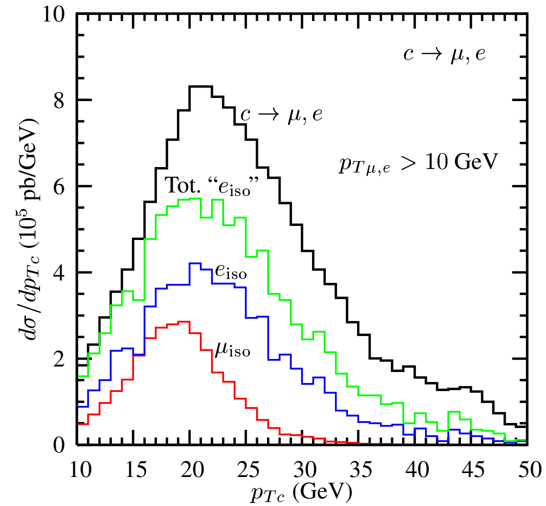

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Fold in $c\bar{c}$ production.

The story repeats for c decays

1 twist: D decays have many pions

$\pi^{\pm}$ fake e at $\sim 10^{-4}$

$\Rightarrow$ Large "$e_{\rm iso}$" rate

Summary: Isolation cuts have limited impact

For the isolated leptons, our simulations suggest:

- $\sim 1/2$ of the events pass the usual isolation cuts, because the remnant is just outside whatever “cone” is used for tracking/energy cuts.
- $\sim 1/2$ of the events pass because the lepton took nearly all of the energy. Hence, there is nothing left to reject on.

It is possible to get factors of 2–3 suppression of the heavy-flavor background by using tighter cuts. Risk is that signal is also suppressed

Nature of the problem: More than 0.5% of all produced b and c quarks are observed as isolated leptons AND $\sigma^{b\bar{b}}_{\mathrm{inclusive}} \sim 5 \times 10^8$ pb at LHC.

Although the decay leptons are “relatively soft”, their associated backgrounds extend well into the signal region of relatively large mass New Physics, e.g., $H \to WW \to l^+l^-\not{E}_T$ with $M_H \sim 150$–200 GeV and SUSY $\tilde{\chi}^+_1\tilde{\chi}^0_2$ for mSUGRA points that exhibit a large trilepton signature.

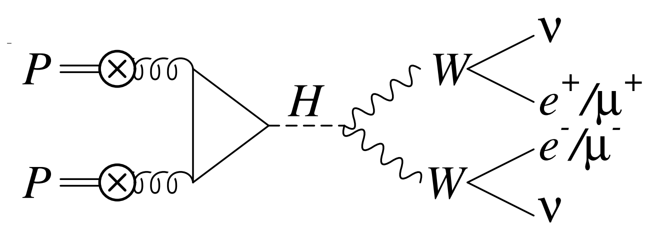
Dileptons at the Tevatron and LHC

The foil:

Higgs production and decay to WW

Z.S., E. Berger, PRD 74, 033008 (2006)

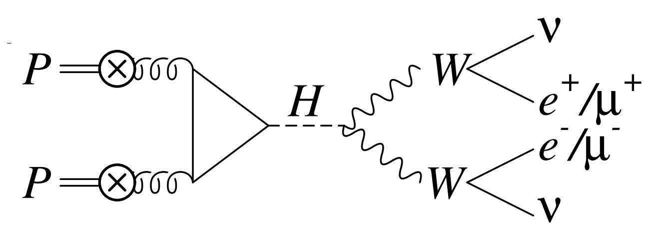
Dileptons and the Higgs



Higgs decays through W^+W^- to opposite-sign dileptons is expected to give the largest significance signal for $135 < M_H < 219$ GeV

CDF, DØ, ATLAS, and CMS have devoted substantial effort to this channel. With 3 fb^{-1} each, CDF, DØ claim to exclude at 95% CL a SM Higgs boson with $M_H \sim 160$–170 GeV arXiv:0903.4001

Dileptons and the Higgs



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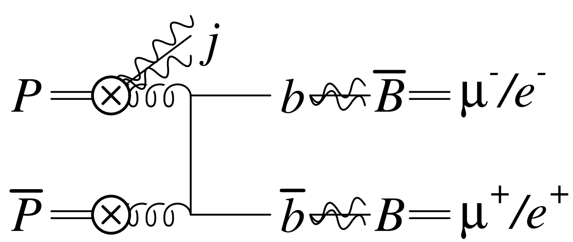
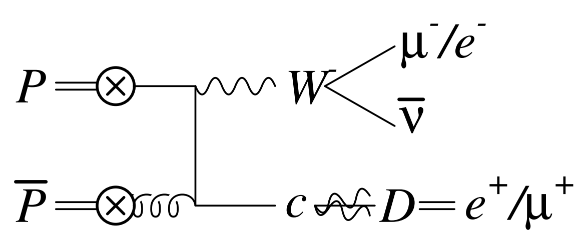
In addition to continuum WW, Z/γ^*, and $t\bar{t}$ contributions, many other QCD and EW processes can provide backgrounds.

These include processes with heavy flavors:
$b\bar{b} + X$, $c\bar{c} + X$, Wc, $Wc\bar{c}$, $Wb\bar{b}$, single-top

We redid the DØ and ATLAS analyses, including full detector simulations, but included isolated leptons from heavy flavor (b, c) decays.





...

Detailed simulations for Tevatron and LHC

- DØ: Has published data, has ongoing analyses, with $S/B \sim 1/30$.
- ATLAS: Has simulations and expects $S/B \sim 1$.

There are two classes of backgrounds with heavy-flavor leptons:

1. Wc, $Wb\bar{b}$, $Wc\bar{c}$, Wb, single-top — All have 1 real W plus 1 HFL.
2. $b\bar{b}$, $c\bar{c}$ — Both have 2 HFL.
   Both have mb cross sections, w/ only 10^4 suppression from isolation.

Simulation method

- for $H \to WW$ and continuum WW use PYTHIA with NLO K factors.
- Wc/Wb use MadEvent fed through PYTHIA with NLO K factors.
- Single-top, $Wb\bar{b}$, $Wc\bar{c}$, normalized to ZTOP/MCFM differential NLO.

PYTHIA output is fed through **modified** PGS simulation that reproduces DØ and ATLAS full detector results to 10%.

$H \to W^+W^- \to e^+e^-\not{E}_T / e^\pm\mu^\mp\not{E}_T / \mu^+\mu^-\not{E}_T$

Taken from $1/3$ fb^{-1}study, DØ, PRL 96, 011801 (2006)

M_H (GeV)	120	140	160	180	200
$H \to WW^{(*)}$	0.125 ± 0.002	0.398 ± 0.008	0.68 ± 0.01	0.463 ± 0.009	0.210 ± 0.004
Z/γ^*	7.5 ± 1.0	3.8 ± 0.6	4.0 ± 0.7	6.6 ± 0.9	9.9 ± 1.1
Diboson	8.1 ± 0.2	11.7 ± 0.3	12.3 ± 0.3	11.6 ± 0.3	9.6 ± 0.3
$t\bar{t}$	0.11 ± 0.02	0.29 ± 0.02	0.47 ± 0.03	0.66 ± 0.05	0.72 ± 0.05
W+jet/γ	14.2 ± 2.1	5.8 ± 1.2	2.8 ± 0.9	0.7 ± 0.5	0.7 ± 0.5
Multi-jet	0.3 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.1
Bknd sum	30.1 ± 2.3	21.8 ± 1.4	19.7 ± 1.2	19.8 ± 1.1	21.2 ± 1.2
Data	21	20	19	19	14

So the relevant backgrounds are:

DØ: WW, small Drell-Yan, small rate from $\pi^\pm$ faking $e^\pm$

ATLAS: WW, some Wt, small $t\bar{t}$

Is that the end of the story?...

Breakdown of LS/OS leptons at DØ

σ_{ll} (fb):	ee		$e\mu$		$\mu\mu$	
	LS	OS	LS	OS	LS	OS
$H \to WW$	—	0.73 ± 0.04	—	1.26 ± 0.05	—	0.60 ± 0.03
WW	—	12 ± 1	—	20 ± 1	—	9.3 ± 0.9
$b\bar{b}(j)$	—	2.1	—	5.6	—	24
Wc	0.8 ± 0.4	2.3 ± 1.1	1.1 ± 0.4	3.7 ± 1.8	—	3.1 ± 2.2
$Wb\bar{b}$	0.4 ± 0.2	0.4 ± 0.1	2.1 ± 1.6	1.3 ± 0.4	2.5 ± 1.6	2.0 ± 1.1
$Wc\bar{c}$	1.4 ± 0.5	1.1 ± 0.4	1.0 ± 0.2	1.6 ± 0.3	1.0 ± 0.4	0.9 ± 0.2
all else	0.1	1.6	0.3	0.3	0.04	0.1

$b\bar{b}$ more than doubles the background to $\mu^+\mu^-$.

Other channels see 50% increases.

Is this consistent with the DØ result?

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Is this consistent with the DØ result? Yes! to within 1–2σ.

Should they see it? The experiments do not have absolute normalized predictions. Instead, they fit WW and Drell-Yan, etc. to data.

The leptons are there, just misclassified.

What we want is to understand all of the physical processes at play.
For that, we have to measure the backgrounds. . .

ATLAS-like search for 160 GeV Higgs

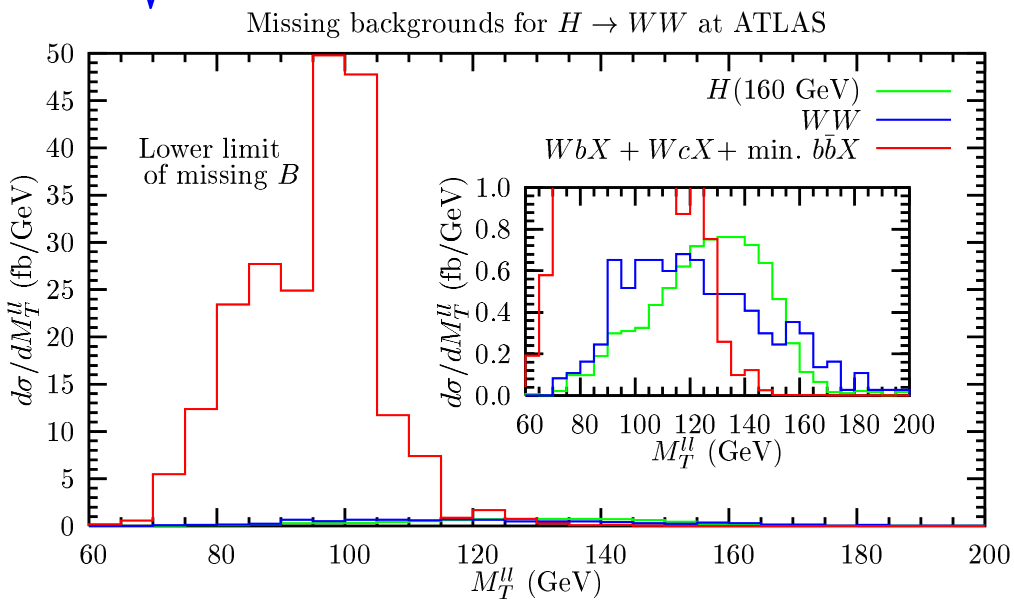
Cut level	$H \to WW$	WW	$b\bar{b}j^{\star}$	Wc	single-top	$Wb\bar{b}$	$Wc\bar{c}$
Isolated $l^+l^- > 10$ GeV	336	1270	> 35700	12200	3010	1500	1110
$E_{Tl_1} > 20$ GeV	324	1210	> 5650	11300	2550	1270	963
$\not{E}_T > 40$ GeV	244	661	> 3280	2710	726	364	468
$M_{ll} < 80$ GeV	240	376	> 3270	2450	692	320	461
$\Delta\phi < 1.0$	136	124	> 1670	609	115	94	131
$\lvert\theta_{ll}\rvert < 0.9$	81	83	> 1290	393	68	49	115
$\lvert\eta_{l_1} - \eta_{l_2}\rvert < 1.5$	76	71	> 678	320	48	24	104
Jet veto	41	43	> 557	175	11	12	7.4
$130 < M_T^{ll} < 160$ GeV	18	11	—	0.21	1.3	0.04	0.09

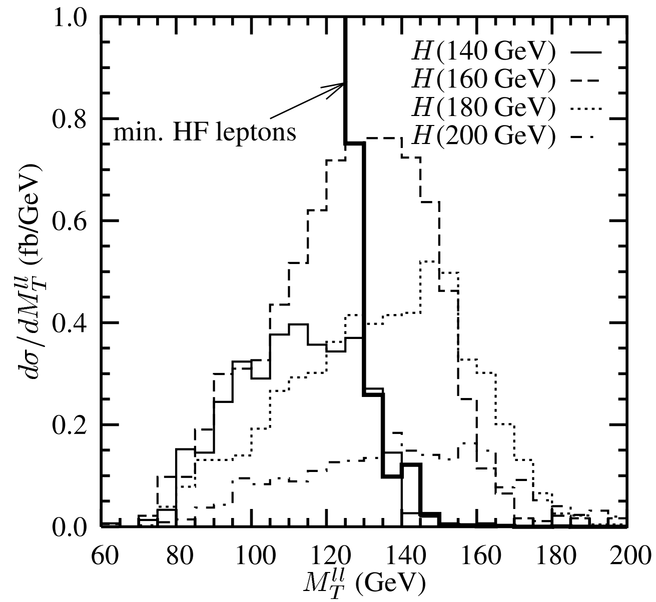
The biggest difference in this analysis is that cross sections are bigger, so the cuts are tighter.

- After the $\not{E}_T$ cut, all real power comes from the M_T^{ll} cut.
  Warning: Numbers can be deceptive!
- $S/B \sim 1$ at LHC, but let's look at M_T^{ll} distribution.

Transverse mass distribution after cuts

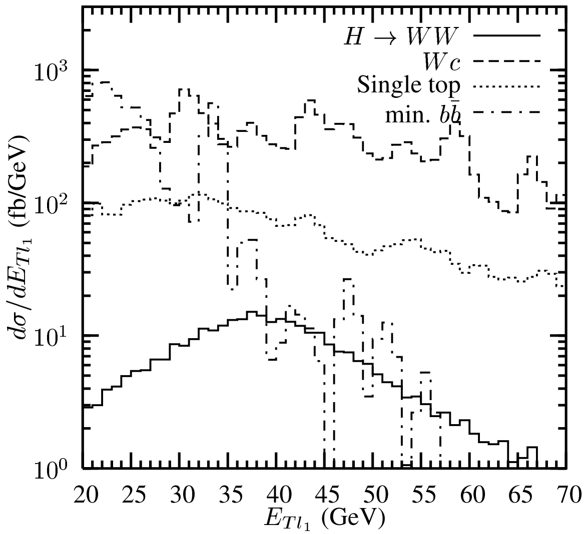
- Cannot reconstruct a Higgs boson mass peak from $H \to WW^* \to l^+l^-\nu\bar{\nu}$; use ‘transverse mass’ as an estimator; $M_T^{l\bar{l}} = \sqrt{2p_T^{l\bar{l}}\not{E}_T(1-\cos(\Delta\phi))}$

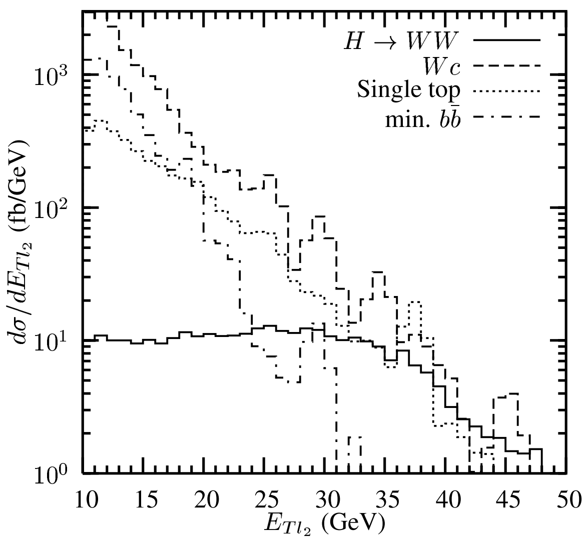




- Heavy flavor background is more than 50 times previous background estimates when $M_T^{ll} < 110$ GeV; a tail extends through the entire signal region

One very effective new cut . . .





Most variations of cuts do not help much.

One could try to raise the cut on p_{Tl_1}.

- No help vs. anything with a W.
- Even $b\bar{b}$ does not decrease fast enough. Recall, an "isolated lepton" from a B is usually not soft compared to the B.

However, the second lepton p_T falls exponentially.

So raise the cut: $p_{Tl_2} > 10$ GeV $\Rightarrow p_{Tl_2} > 20$ GeV.

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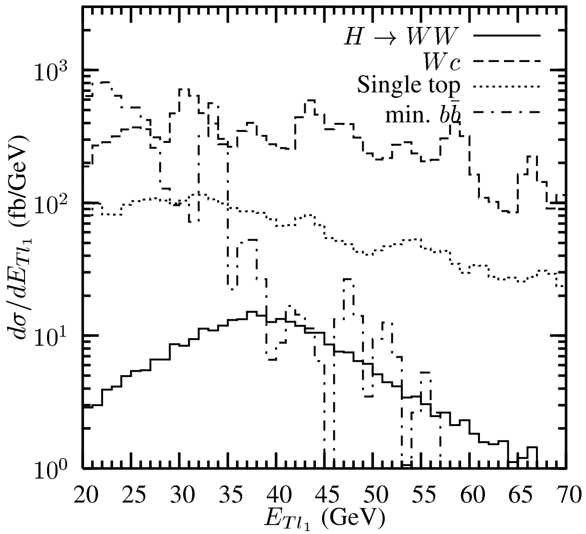

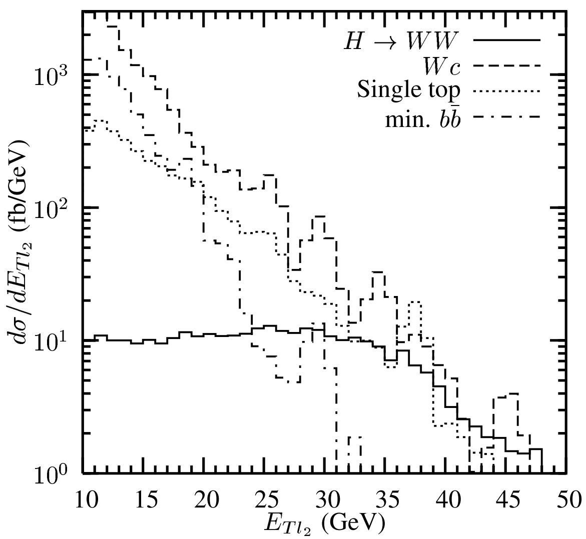

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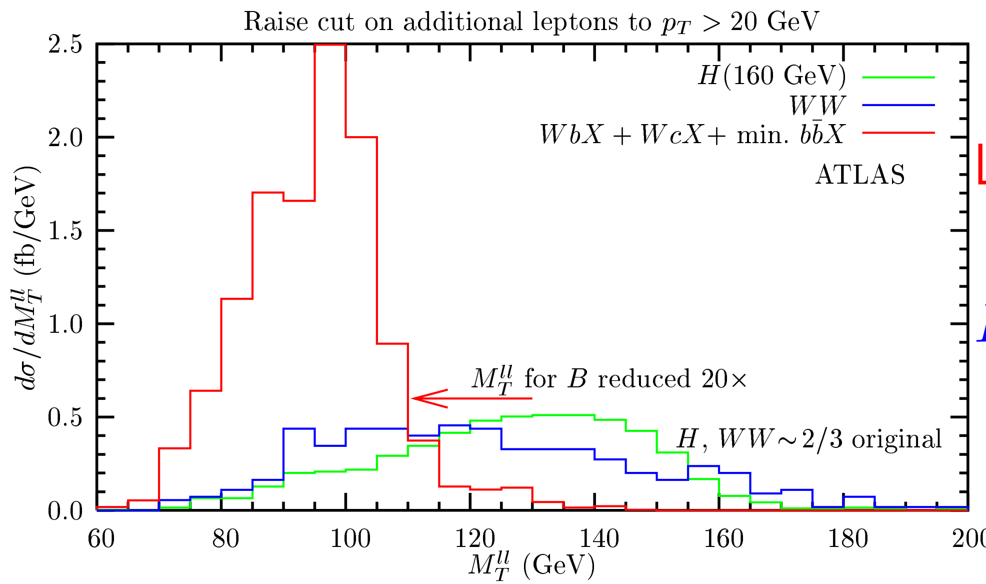


Leading edge 20 GeV lower!

$H \to WW$ survives!

$b\bar{b} \to b\bar{b}/30$, $W+X \to W+X/10$, $t+X \to t+X/5$

Dileptons and $H \to WW$: Summary

(Z.S. and E. Berger, PRD 74, 033008 (2006))

Isolation cuts do not generally remove leptons from heavy flavors as a background to multi-lepton searches. A sequence of complex physics cuts is needed.

1. A full treatment of all physics processes with b and c should be performed in multi-lepton analyses.
2. Heavy-flavor lepton backgrounds cannot be easily extrapolated from more general samples.

   The interplay between isolation and various cuts tends to emphasize small corners of phase space, rather than the bulk.

   Measure the background close to the final cuts
3. Raising the p_T cut on additional leptons suppresses the heavy flavor backgrounds.

   $H \to WW$ signal is barely touched, so this technique should work at the LHC, for $M_H > 130$ GeV.

   Trileptons, or other Higgs channels may be sensitive as well...

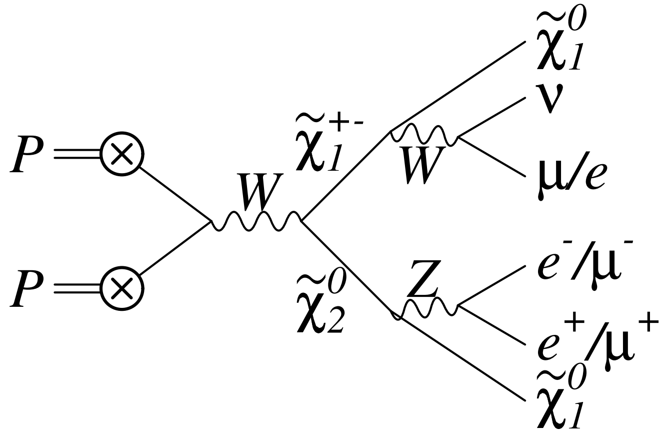
Trileptons at the LHC

The foil:

SUSY chargino/neutralino production

Z.S., E. Berger, PRD 78, 034030 (2008)

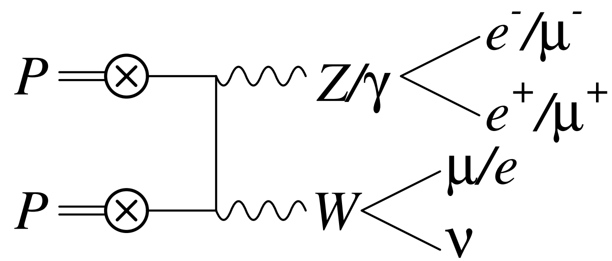
Motivation: Trileptons at LHC



$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to l^+ l^- \, l^{\pm} + \not{E}_T$ is a golden signature of supersymmetry.

CMS and ATLAS have analyses designed to observe this signal.

CMS TDR V.2&Note 2006/113; ATLAS CSC 7



WZ is thought to be the largest source of low-p_T trileptons at LHC.

$W\gamma^*$ is not always included but it should be

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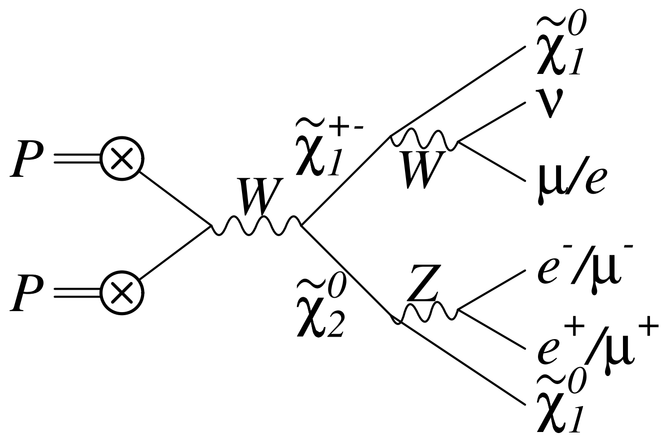

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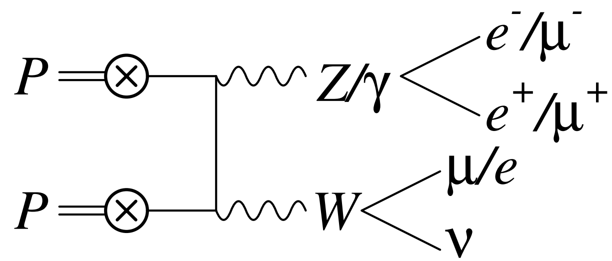
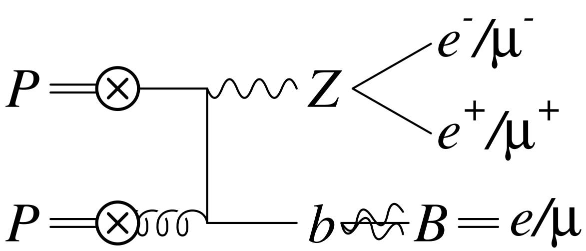
CMS TDR V.2&Note 2006/113; ATLAS CSC 7



WZ is thought to be the largest source of low-p_T trileptons at LHC.

$W\gamma^*$ is not always included but it should be



There are MANY processes with heavy flavors:
bZ/γ, $b\bar{b}Z/\gamma$, cZ/γ, $c\bar{c}Z/\gamma$, $b\bar{b}W$, $c\bar{c}W$, $t\bar{t}$, tW, $t\bar{b}$

How important are leptons from heavy flavor (b, c) decays?

NOTE: All photons are virtual, and split to l^+l^-

SUSY particle masses

We examined the trilepton SUSY signal and the SM backgrounds for 4 SUSY points (all masses in GeV units):

	$\widetilde{\chi}_1^0$	$\widetilde{\chi}_2^0$	$\widetilde{\chi}_1^\pm$
LM1	96.8	178.3	178.1
LM7	90.5	154.8	154.8
LM9	68.7	121.7	122.3
SU2	112.5	171.3	164.0

- LM1, LM7, and LM9 are the SUSY points investigated by CMS. They are a subset that exhibits a large trilepton signature from $\widetilde{\chi}_1^+ \widetilde{\chi}_2^0$ decay.
- ATLAS point SU2 is in the focus point region of mSUGRA parameter space.
- These may already be excluded by WMAP, $b \to s\gamma$, or other data. We use them to make contact with the CMS and ATLAS simulations.

Event simulations

We reproduced the analysis chains described in

1. CMS: CMS TDR V.2&Note 2006/113
2. ATLAS: ATLAS CSC 7

but we included, in addition, the contributions from processes with heavy flavors: bZ/γ, $b\bar{b}Z/\gamma$, cZ/γ, $c\bar{c}Z/\gamma$, $b\bar{b}W$, $c\bar{c}W$, $t\bar{t}$, tW, $t\bar{b}$

Simulation method

- Matrix elements computed in MadEvent (spin correlations included)
- MadEvent results fed through PYTHIA showering.

PYTHIA output is fed through a modified PGS detector simulation that reproduces CMS and ATLAS full detector results to 10%.

Important CMS Analysis Cuts

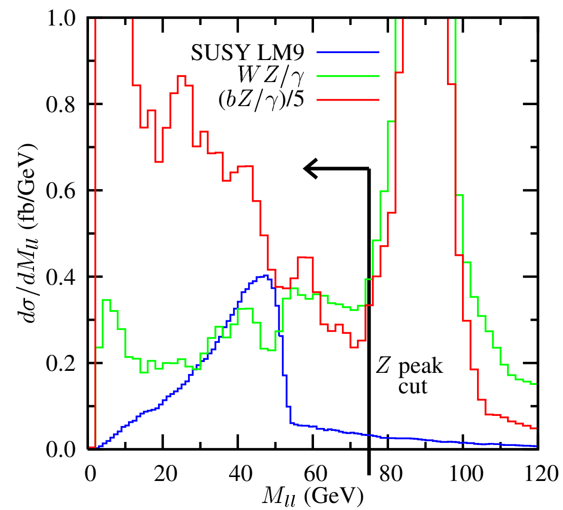
- Require 3 isolated leptons
- Require no jets with $E_T > 30$ GeV
- Require $M_{ll}^{\rm OSSF} < 75$ GeV

Trileptons: SUSY & SM at CMS w/ 30 fb^{-1}

Channel	$N^l = 3$, NoJets	$M_{ll}^{\rm OSSF} < 75$ GeV
LM9	248	243
LM7	126	123
LM1	46	44
WZ/γ	1880	538
$t\bar{t}$	1540	814
tW	273	146
$t\bar{b}$	1.1	1.0
bZ/γ	14000	6870
cZ/γ	3450	1400
$b\bar{b}Z/\gamma$	8990	2220
$c\bar{c}Z/\gamma$	4680	1830
$b\bar{b}W$	9.1	7.6
$c\bar{c}W$	0.19	0.15

Analysis cuts:

- 3 leptons
- No jets ($E_{Tj} > 30$ GeV)
- Remove Z peak (demand $M_{ll}^{\rm OSSF}) < 75$ GeV

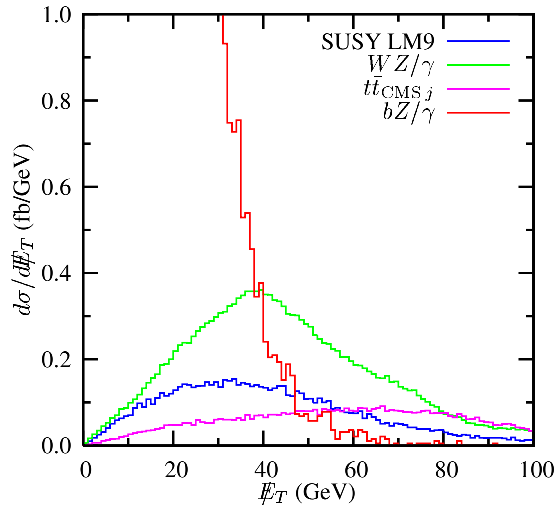


Z+heavy flavor decays are $10\times$ $WZ/\gamma + t\bar{t}$!

Two additional cuts: $\not{E}_T$ and angular correlations

Leptons from SUSY decays are SOFT $\Rightarrow$ Cannot raise p_{Tl} cut.

Missing E_T



Z/γ+heavy flavors – no intrinsic $\not{E}_T$

Comes from misreconstruction, energy lost down beam pipe

Natural $\not{E}_T$ in SUSY points low as well

$\tilde{\chi}_1^0$'s partially balance out

A $\not{E}_T$ cut demanding $\not{E}_T > 30$–40 GeV is very effective

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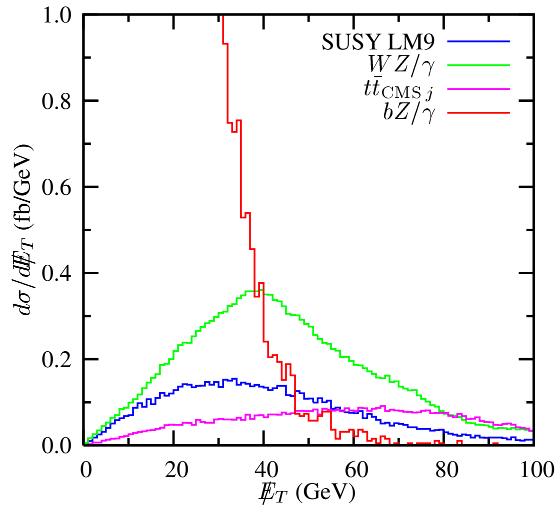

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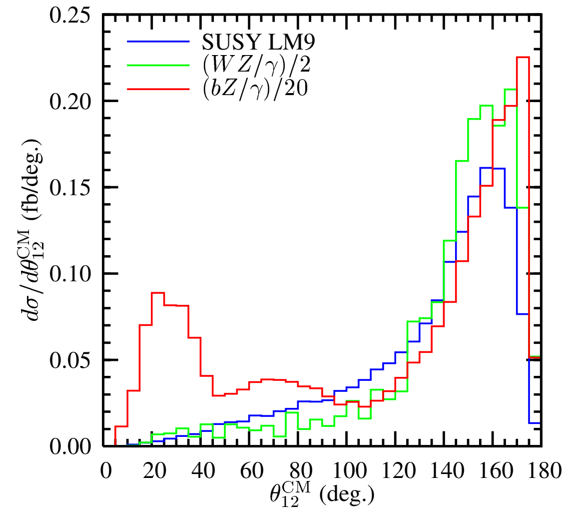
$\not\!\!E_T$ is poorly measured

Angular correlations



Angles measured extremely well

All combinations different ($\theta_{12}^{\mathrm{CM}}$ shown)

Demand $\theta_{12}^{\mathrm{CM}} > 45^\circ$, $\theta_{13}^{\mathrm{CM}} > 40^\circ$, $\theta_{23}^{\mathrm{CM}} < 160^\circ$

Reduces B by 30% for 5% loss of S

Not optimized

Trileptons: SUSY & SM at CMS (+new cuts)

Channel	$N^l = 3$, NoJets	$M_{ll}^{\mathrm{OSSF}} < 75$ GeV	$\not{E}_T > 30$ GeV	Angular cuts
LM9	248	243	160	150
LM7	126	123	89	85
LM1	46	44	33	32
WZ/γ	1880	538	325	302
$t\bar{t}$	1540	814	696	672
tW	273	146	123	121
$t\bar{b}$	1.1	1.0	0.77	0.73
bZ/γ	14000	6870	270	177
cZ/γ	3450	1400	45	35
$b\bar{b}Z/\gamma$	8990	2220	119	103
$c\bar{c}Z/\gamma$	4680	1830	69	35
$b\bar{b}W$	9.1	7.6	5.6	5.3
$c\bar{c}W$	0.19	0.15	0.12	0.11

Significance of SUSY point LM9 in 30 fb^{-1}

1. Our calculations are LO.
   NLO K-factors are large (1.5–2) on most processes,
   BUT, jet veto will reduce this.

2. ISR is not well determined
   The rate of > 30 GeV jets can be changed by a factor of 4 depending on assumptions in PYTHIA about ISR.

We present our calculation, and one that scales down B by 4 to show the range of possible significances

	$N^l = 3$, NoJets	$M_{ll}^{\mathrm{OSSF}} < 75$ GeV	$\not{E}_T > 30$ GeV	Angular cuts
$S/\sqrt{B}_{\mathrm{LM9}}$	1.33	2.07(1.79)	3.93(3.74)	3.94(3.79)
$S/\sqrt{B}_{\mathrm{LM9}}^{\mathrm{CMS}\,j}$	2.63	4.09(3.54)	7.78(7.39)	7.79(7.49)

(Parentheses include leptons from fakes from CMS Table 6, Note 2006/113)

We will not know which ISR estimate is correct until we measure it at LHC

Summary of trileptons

(Z.S. and E. Berger, PRD **78**, 034030 (2008))

1. Heavy-flavor (b, c) decays to leptons dominate low-p_T isolated leptons at LHC
   Trileptons from Z/γ^*+heavy flavors (HF) $\sim 10\times$ all other backgrounds
2. Raising minimum p_T is not viable for SUSY signal, but other cuts work:
   - Require $\not{E}_T > 30$ GeV, $Z/\gamma^* + \mathrm{HF} \rightarrow Z/\gamma^* + \mathrm{HF}/30$ Challenging
   - Impose cuts on well-measured angles, Z/γ^*+HF reduced by 30%
3. Overall normalization is dominated by assumptions regarding ISR
   Large uncertainty in the effectiveness of jet veto

   If large ISR exists, may want to loosen jet veto to recover SUSY signal
   ISR questions should be resolved with initial data from LHC
4. Any signal that has low-p_T leptons MUST consider the background from heavy flavor (b, c) decays. Analyses of SUSY exclusion limits should include this (neglected) background.

Overall lesson: Precise understanding of all SM physics processes will enable confident discovery claims.

Dimuons from $b\bar{b}$ decays in the CDF data

The foil:

A Trilepton search at CDF (PRD 79, 052004 (09))

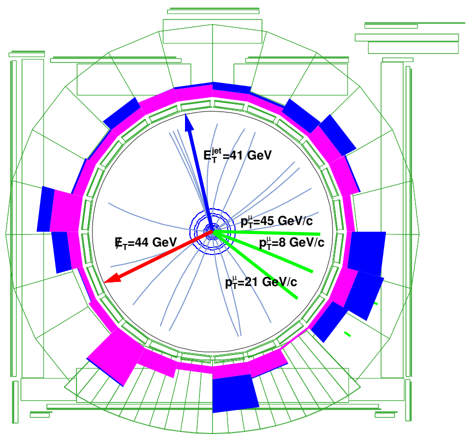
Z.S., E. Berger, arXiv:0912.xxxx

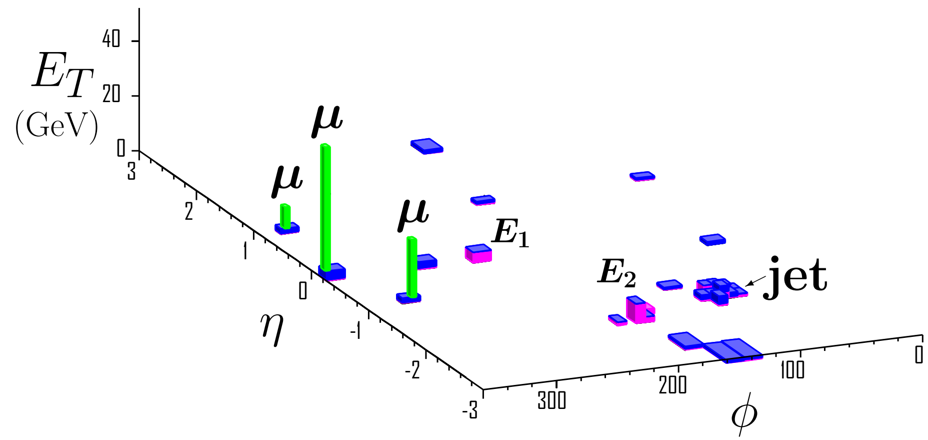
CDF Motivation: SUSY Trileptons

CDF is looking for the golden signature of supersymmetry,

$\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0 \to l^+l^-\,l^{\pm}+\not{E}_T$

Specifically, they are looking for anomalous $\mu\mu + e/\mu + \not{E}_T$.





CDF, PRD 79, 052004 (09)

Is this SUSY or background?

Searching the data

In our dilepton study (PRD **74**, 033008 (06)) we recommended measuring the production of isolated muons from $b\bar{b}$ production by varying isolation cuts to extract the $\mu_{\rm iso}$ fraction.

That is exactly what CDF has now done!

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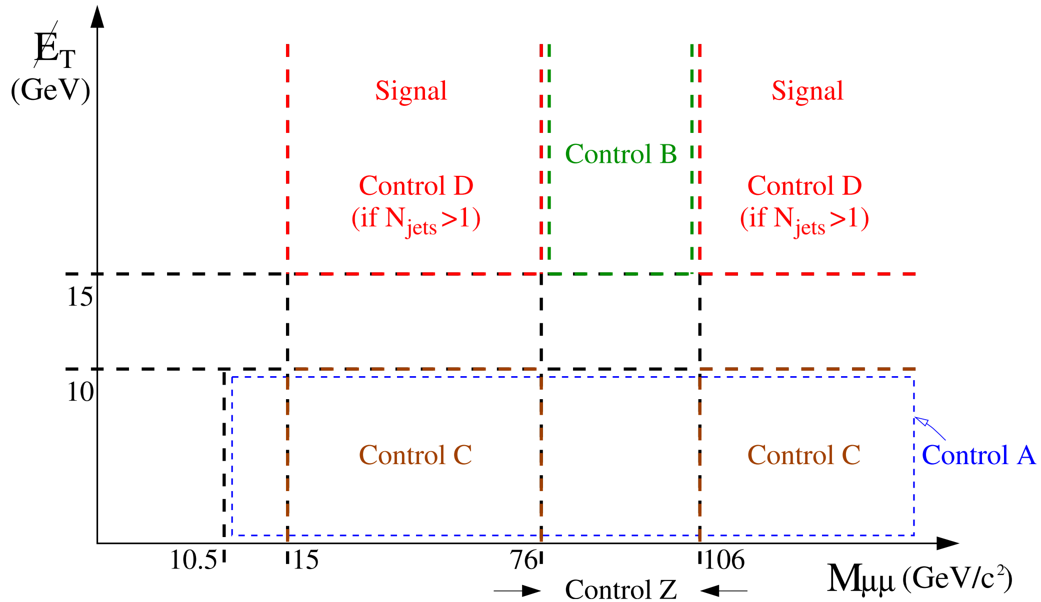


ALL previous trilepton studies at the Tevatron had ignored heavy-flavors as a source of isolated leptons.

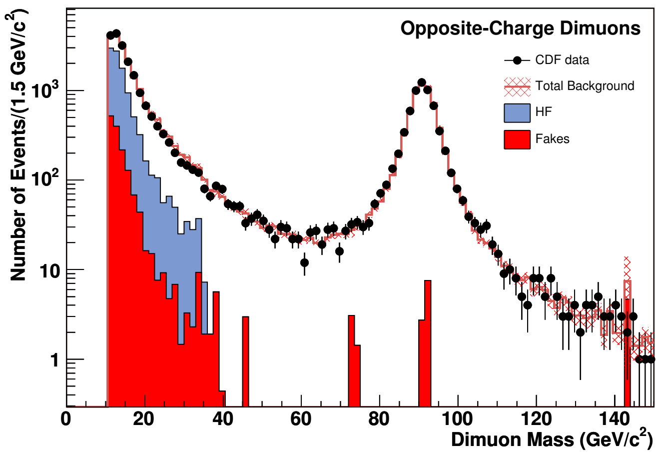
CDF established several control regions in the $\not{E}_T$–$M_{\mu\mu}$ plane.
—Dimuons are used because the the signal is large and clean.

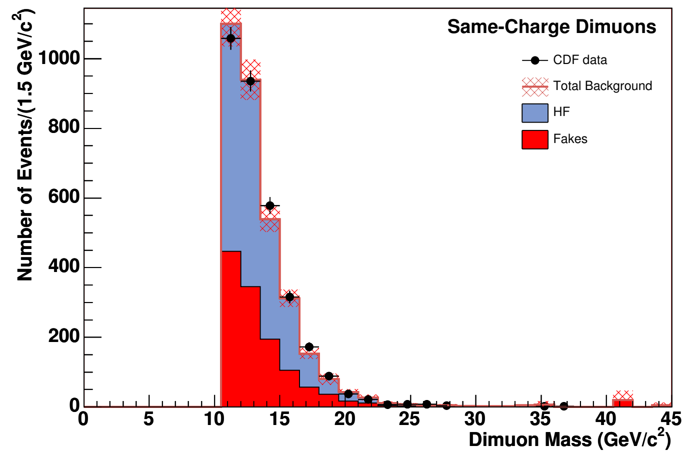
Each component of background is measured explicitly.

CDF result

CDF, PRD 79,052004 (2009)

Looking in the dimuon sample, CDF varies the impact parameter cut, and fits for $b\bar{b}$ in both opposite-sign and same-sign channels.





Region	DY	HF	Fakes	Diboson	$t\bar{t}$	**Total SM expected**	**SUSY expected**	**Observed**
Control Z	6419 ± 709	-	10 ± 11	2.4 ± 0.2	1.18 ± 0.14	6433 ± 712	0.30 ± 0.07	6347
Control A	14820 ± 2242	9344 ± 1612	2294 ± 1148	1.03 ± 0.09	0.12 ± 0.03	26459 ± 1429	0.9 ± 0.2	26295
Control B	217 ± 25	-	9 ± 7	1.7 ± 0.2	0.27 ± 0.05	227 ± 26	0.5 ± 0.1	253
Control C	5770 ± 1043	2238 ± 384	466 ± 234	0.49 ± 0.07	0.02 ± 0.01	8474 ± 857	0.7 ± 0.2	8205
Control D	7.8 ± 1.5	9 ± 4	0.3 ± 0.3	0.21 ± 0.07	4.1 ± 0.4	22 ± 5	1.8 ± 0.4	23
Signal Reg.	169 ± 30	90 ± 20	49 ± 25	6.5 ± 0.4	0.96 ± 0.11	315 ± 37	17 ± 3	297

Conclusion: Leptons from heavy-flavor decays are a significant background.

They are comparable to Drell-Yan at low M_{ll} and low $\not{E}_T$.

Comparing to CDF

Z.S., E. Berger, arXiv:0912.xxxx

We run the same MadEvent fed through PYTHIA and into our detector simulation used before and see what we predict for each control region. Our results are normalized to the Z peak. Our DY and $b\bar{b}$ include NLO K-factors.

	CDF		Our study	
Region	DY	$b\bar{b}$	DY	$b\bar{b}$
Control Z	6419 ± 709	—	6419 ± 752	—
Control A	14820 ± 2242	9344 ± 1621	14222 ± 1615	5118 ± 584
Control C	5770 ± 1043	2238 ± 384	4898 ± 584	924 ± 117

Conclusions:

- We underestimate the real background from $b\bar{b}$.
- Isolated muons from heavy flavor decays are a significant fraction of low-p_T data samples.
- We believe all of our results have been conservative.

What have we learned about leptons from heavy-flavor (b,c) decays?

(Z.S., E. Berger, PRD 74, 033008 (2006); PRD 78, 034030 (08); arXiv:0912.xxxx)

1. Heavy-flavor (b, c) decays to leptons are in the Tevatron data and will dominate low-p_T isolated leptons at LHC:
   Dileptons from $b\bar{b}/c\bar{c}$ and $W c$ $\sim 50\times$ all other backgrounds
   Trileptons from Z/γ^*+heavy flavors (HF) $\sim 10\times$ all other backgrounds
   A good estimate is to treat $1/200$ of every b or c as an isolated lepton.

2. For $H \to WW$, raising the minimum p_T is the most effective way to suppress leptons from HF
   DØ and CDF significance is not likely to change, but an explicit demonstration of control over these backgrounds would greatly strengthen their results.

3. For SUSY trileptons, raising minimum p_T is not viable, but could:
   Require $\not{E}_T > 30$ GeV, $Z/\gamma^* + \mathrm{HF} \to Z/\gamma^* + \mathrm{HF}/30$ Hard to measure low $\not{E}_T$
   Impose cuts on well-measured angles, Z/γ^*+HF reduced by 30%

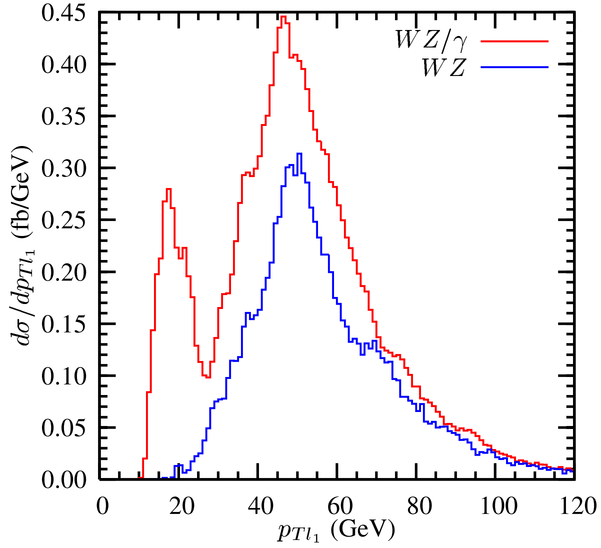
4. CDF has measured isolated leptons from heavy-flavor decays
   It can be comparable to Drell-Yan.

Any signal that has low-p_T leptons MUST consider the background from heavy flavor (b, c) decays

BACKUPS

Importance of the virtual photon

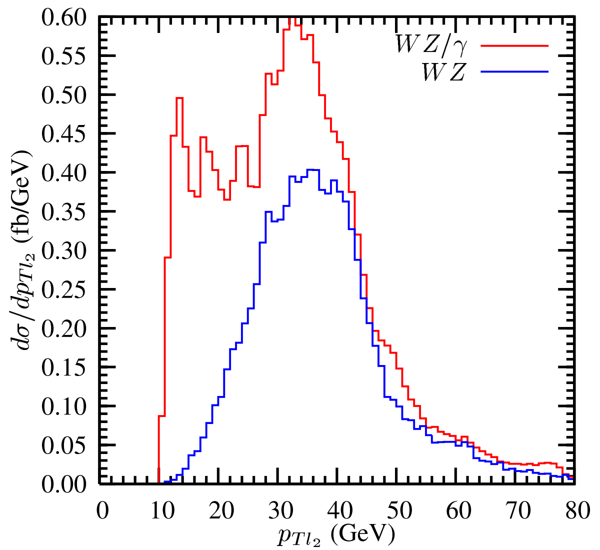
Simulations of WZ based on PYTHIA do not include virtual photons.

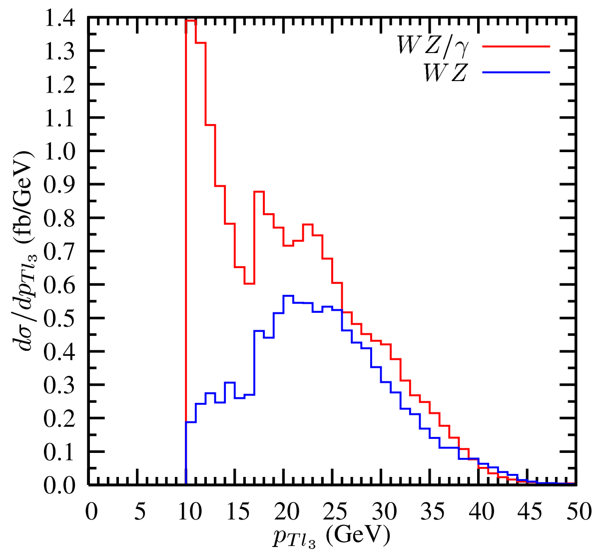


Nearly $1/2$ of the trilepton background from WZ/γ is from $W\gamma^*$ alone.

Matrix elements that include virtual photons are important for studies of low-p_T leptons.

(p_{Tl} spectra after M_{ll}^{OSSF} cut)





Pure QCD background to trileptons

CMS estimates $jjj \to lll < 5$ events in 30 fb^{-1}

What about $b\bar{b}b\bar{b}$, $b\bar{b}c\bar{c}$, $c\bar{c}c\bar{c}$?

We cannot simulate this directly in our lifetimes ($\sim 10^3$ CPU years)

Estimate 3 sources of $b\bar{b}b\bar{b}$ for 30 fb^{-1}

1. Direct $b\bar{b}b\bar{b}$: ~500 events
   Use $Wb\bar{b}$ to estimate $P(b \to \mu_{\rm iso})$: $\sigma_{b\bar{b}b\bar{b}} \times (7.5 \times 10^{-3})^3$
2. Multiple interactions: ~600 events
   10 interactions $\times \sigma^2_{b\bar{b}}/\sigma^{\rm Tot}_{\rm inelastic}$
3. Multiple scattering, gluon splitting: $\sim 10^3$ events

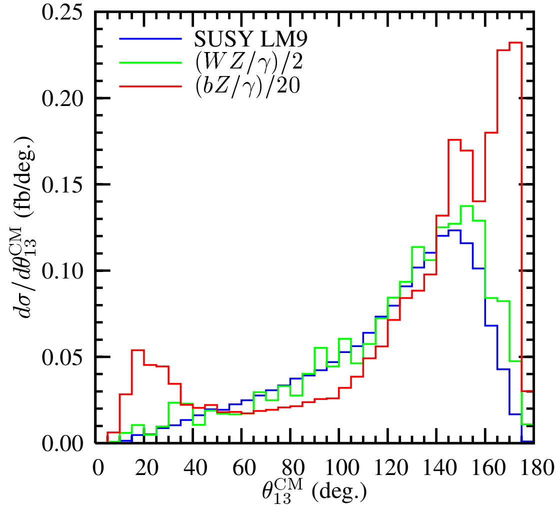
Note that K factors could be as high as 5.5

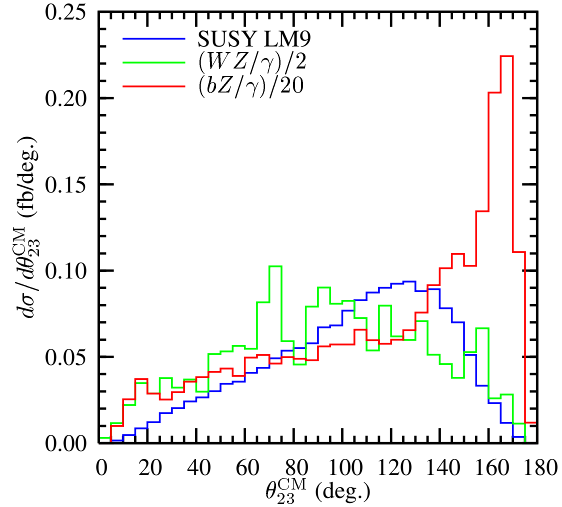
A. Del Fabbro, D. Treleani, PRD66, 074012 (02)

Scaling results from Z.S., E.L. Berger, PRD 74, 033008 (06),
the $\not\!\!E_T$ cut should remove nearly all of these.

Other angular correlations

Angles are well-measured, and defined in the trilepton CM frame.





Suggested cut: $\theta_{13}^{\rm CM} > 40°$

Suggested cut: $\theta_{23}^{\rm CM} < 160°$

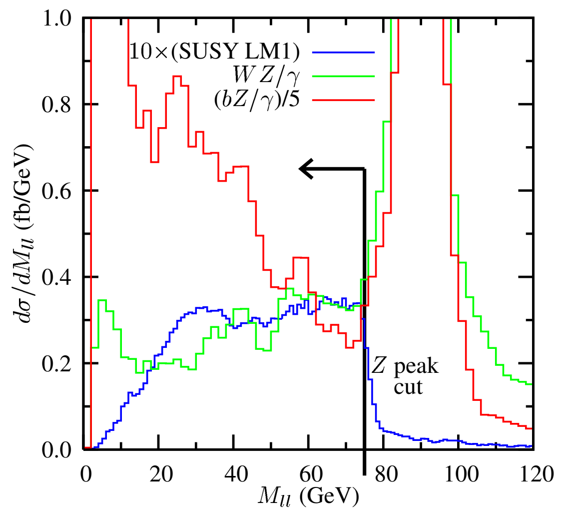
These cuts are almost free, and not optimized.

5% signal decrease, but 30% backgound decrease

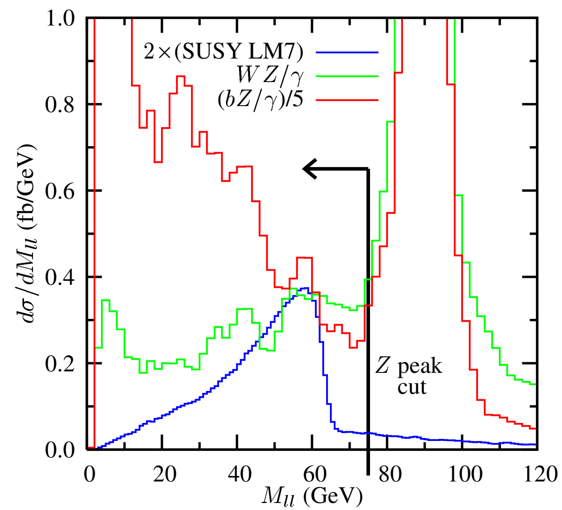
CMS SUSY points LM1, LM7

Representative opposite-sign same-flavor (OSSF) invariant masses

LM1



LM7



Signal endpoint above Z-peak cut and signal is small

LM7 similar to LM9, but smaller

Dimuon transverse mass (normalized to data)